Performance Assessment of a Portable Improved Bio-Ethanol Gel Clean-Cook stove

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ABSTRACT: This article presents the potential of gel ethanol fuel to reduce indoor emissions using an improved clean cook stove. The performance of the fabricated stove was analyzed. This was based on the fuel efficiency, environmental and human health impacts during utilization of bio-ethanol gel fuel and the developed stove. The improved bio-ethanol gel cookstove developed was compared with two other cookstoves in terms of performance. The developed stove had vermiculite insulation with a low thermal conductivity of 0.17 W/mK which maintains a combustion temperature of 691°C. The calorific value of the bio-ethanol gel fuel was obtained as 18.5 MJ/kg, with an efficiency of 75%. The combustion temperature of the improved stove was 12.8% improved against the existing stoves. The moderate energy efficiency and other performance indicators of the improved stove showed that it was the most suitable stove for home use.

KEYWORDS: Ethanol gel, fuel efficiency, Emissions, Cooking, stove

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INTRODUCTION

It has become evident that people globally rely on biomass, as the main source of energy for household purposes, such as cooking, space heating and lighting. According to Ferriz Bosque *et al*. [1], around 2,800 million people worldwide burn solid bio-fuels for their basic energy needs, more than half of the population in developing countries [2]. Under developed countries and developing countries use bio-energy as the main energy source for households. In a traditional oven, in most cases, a tripod construction is used on which the pot rests [3]. This combustion usually results in an incomplete combustion process that directly releases harmful pollutants such as particles and carbon monoxide, contributing to high morbidity and mortality rates [4]. According to the World Health Organization, four million people die prematurely worldwide each year from indoor air pollution [5]. In addition, it not only directly affects health but also directly impact social justice and community development [6-8].

Cooking being the main activity is mostly done indoors within a confined area, with prolonged exposure to emissions from inefficient combustion. These emissions cause major health ailments to humans, in addition to rise in emission of Greenhouse Gases (GHGs) that affect environment. Apart from ill health to users, the inefficient combustion and heat transfer of biomass cook stoves consumes excess fuel resulting to depletion of forests and increase of time spent fetching suitable fuel. Further, the combustion of this traditional biomass using inefficient cook stoves releases pollutants such as particulate matter, carbon monoxide, oxide of nitrogen, volatile organic compounds and polycyclic aromatic hydrocarbon. These pollutants have detrimental effects on human health and the environment.

The performance (thermal efficiency) of biomass stoves are determined by various factors such as stove construction, type of fuel supply, and combustion temperature [9-12]. For example, Darlami *et al*. [13] reported the design of a Traditional Nepali Chef with stove modified with mud. Similarly, Oyejide *et al*. [11] has adaptively designed a modular oven with briquettes of an invasive pleustophytic herb (water hyacinth). Furthermore, Perez *et al*., [14] designed a Furnace 3kW for biomass

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gasification with a Fuel from agricultural waste as an alternative to charcoal. Shanono*et al*., [12] also demonstrated the feasibility of using jatropha oil Bio Stove and Neem Oil Bio Stove used crude oil blends Jatropha and Neem with kerosene as biofuels. From an ecological point of view, the stoves had reduction in amount of harmful emissions with the fuel used, a mixture of kerosene and vegetable oils.

To this end, advanced cooking technologies that offer more efficient stoves and cleaner fuels remains the best bet. As this phenomenon, improves health, reducing deforestation and protecting lives [15]. An alternative to biomass fuels, bio-ethanol is a clean-burning, alcohol-based fuel made with modern distillation technology to replace biomass fuels [16]. Ethanol is made from it fermentable sugars and can be made from four main categories: sugar crops such as sugar cane and sweet sorghum; cereal crops such as corn and sorghum; roots and tubers like beets and cassava, and fruits like mango, cashew, bananas and melons [17].When this alternate fuel is utilizes in a clean cook stove, it reduces emission of toxic substances.
Clean cook stoves with bio-ethanol fuel can reasonably reduce the disadvantages associated with biomass fuels. Therefore, this work aims at developing of a clean cook-stove and bio-ethanol gel fuel as energy source. The performance of the stove and fuel developed were tested using parameters like burning rate, specific fuel consumption, calorific value, thermal efficiency, and cooking time as compared to cooking effect of conventional fuel like kerosene and charcoal.

2 METHODS

This section shows a thorough description of materials, equipment and procedures used for carrying out the experiment.

2.1 Bio-Ethanol Gel Materials and Preparation

The materials used include: cassava, Calcium Carbonate, Acetic acid, Water, Isopropyl alcohol, 3.5%, HNO_3,$NaNO_2$, 2% NaOH, and High-speed mixers.

Samples/Enzyme Collection

The raw material cassava waste (peel and pulp) was obtained from garri processing plant at Eziama Achara Uturu, Abia State. Nigeria. The enzymes used in this study were a-amylase. β-giucanase and amylo glucosidase which were obtained from the Department of Chemical Engineering, Gregory University Uturu, Abia State. Nigeria. The samples were sorted and then washed under running water to remove sands and other dirt particles. Samples were sun dried for about two weeks, milled into a powder form and stored in a polythene bag.

2.2 Digestion of Cassava Wastes (Peel and Pulp)

50 grams of powdered cassava peels and pulps were weighed in six different conical flasks and 500 ml of distilled water was added to each. They were heated to boil for 40 minutes. They were allowed to cool and 2ml of enzymes (Termamyl, AMG. Cereflo) were added in each flask and incubated at 50°C in water bath for two hours with stirring every 20 minutes. Then, the temperature was increased for 5 minutes and then filtered using filter paper Whitman No. 1.

2.3 Fermentation of Cassava Waste with Yeast

500 grams of cassava pulp (ground) were measured out into a clean conical flask and 200ml of water added, the solution was heated for 10minutes at 90°C. The temperature was reduced to 70°C and 4ml of Termamyl was added and allowed to stand for one hour followed by filtration of the solution using filter paper Whatman No 1. The process was repeated using Cereflo plus Termamyl, 2mL each but at the temperature of 55°C. Also, the process was repeated using AMG plus Termamyl, 2mL each but at the temperature of 55°C. The filtrates were sterilized in an autoclave at 121°C for 15 minutes. Then 100ml of each cool sample were taken and 15ml of inoculum was added into the samples and stored in refrigerator. From the remaining filtrate, 50ml in each case was stored in a freezer for further analysis.

2.4 Distillation Process

The distillation apparatus was set up for the distillation of fermented samples. The specific gravity of the distillates was determined by dividing the weight of distillate by the weight of equal volume of distilled water. Furthermore, the percentage ethanol in the distillates was determined from the Association of Official Analytical Chemist. Physiochemical Properties and Proximate Analysis of Sample were carried out according to AOAC [19].

2.5 Bio-ethanol Gel Formulation

Thickener was added to Isopropyl alcohol which has been obtained from cassava to form Isopropyl alcohol gel. 500mL of Isopropyl alcohol was poured into a beaker and stirred with a mixer at a speed of 1000 rpm, while 80.5 grams of Calcium acetate was added slowly. The mixture was stirred continuously with a mixer for 45 minutes. Then 1mL of NaOH was added to form the bio-ethanol gel. The processed bottled bio-ethanol gel is as seen in Figure 1.

Figure 1: Bottled Bio-ethanol Gel

2.6 Design of Bio-ethanol Gel Cookstove

The Bio-ethanol Gel Cookstove was designed using the 316L stainless steel. Other materials utilized include ceramic fibreglass insulation blanket, fibreglass cloth, steel wire, flame switch, inner lid, outer lid, shell, tripod, and gel. The ceramic fibreglass insulation blanket with a high melting temperature rating of 1260^0C, which serves as a gel reservoir placed inside the shell. The fibreglass cloth, with a higher melting temperature rating of 1482^0C, which serves as a heat backing fibre was placed on top of the gel reservoir, while the steel wire, with a melting temperature rating of 1100^0C, which serves as a heat pass was placed on top of the heat backing fibre. The steel wire and mounted flame switch were covered with an inner lid and outer lid respectively, and the tripod was mounted to complete the full assembly of the Bio-ethanol Gel Cookstove. Figure 2 shows the isometric presentation of the cook stove with the labelling of its major parts.

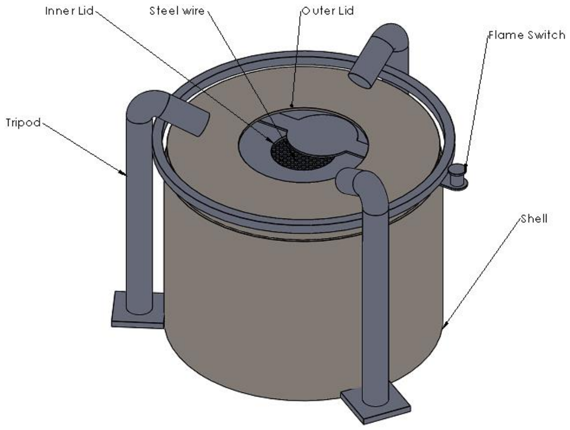

Figure 2: Bio-ethanol Gel Cookstove

2.7 Design Considerations

2.7.1 Design of the Total Surface Area and Volume of the Shell

The shell serves as a gel reservoir case. The total surface area and: volume was calculated as: Hint Shell diameter, d = 0.21m, Shell height, h = 0.15m.

Total surface area = $\pi\frac{d}{2}(\frac{d}{2}+2h)$

$$= \pi\frac{0.21}{2}(\frac{0.21}{2} + 2\times 0.15) = 0.1336m^2$$

Volume = $\frac{\pi d^2}{4} h = \frac{\pi \times 0.21^2}{4} \times 0.15$ = 0.00520m^3 or 5.2 litres

2.7.2 Combustion Air Requirement

The principal constituent of the bio-ethanol gel is ethanol($C_2H_5\ OH$). Thickening agent used to make the fuel pour like gel is calcium acetate$C_4H_6CaO_4$). Both the chemical formula of the fuel and the combustion reaction it entails as given below.The general combustion equation is given as:

$$C_nH_mO_y + (n + \frac{m}{4} - \frac{y}{2})(O_2 + 3.76N_2 \rightarrow nCO_2 + \frac{m}{2}H_2O + 3.76(n + \frac{m}{4} - \frac{y}{2})$$

$$C_2H_5OH + \ C_4H_6CaO_4 becomes C_6H_{12}O_5Ca$$

Going by the general combustion equation, $C_nH_mO_y = \ C_6H_{12}O_5Ca$

It implies that n =6, m = 12 and y = 5

$$C_6H_{12}O_5Ca + 6.5O_2 + 24.44N_2 \ \rightarrow 6CO_2 + 6H_2O + 24.44N_2 + Ca$$

(A/F) stoich. = $\frac{6.5 \times 32 + 24.44 \times 28}{12 \times 6 + 1 \times \ 12 + 16 \times 5 + \ 40} \approx 4.4$

Therefore, (A/F) stoich. = 4.4kg air/kg fuel

$$\phi = \frac{(A/F)\ stoich.}{(A/F)\ actual}$$

According to Samuel (2009), actual air supply is 20% in excess of stoichiometric value. Actual air / fuel ratio is (A/F) actual = $\frac{20}{100} \times 4.4 + 4.4$ = 0.88 + 4.4 = 5.28 air/kg fuel.

Therefore, (A/F) actual = 5.28kg air/fuel.

ϕ = 4.4/5.28 = 0.833

Since 0.833 < 1, it means the mixture of the bio-ethanol gel and air is a lean mixture. There is therefore likelihood of complete combustion.

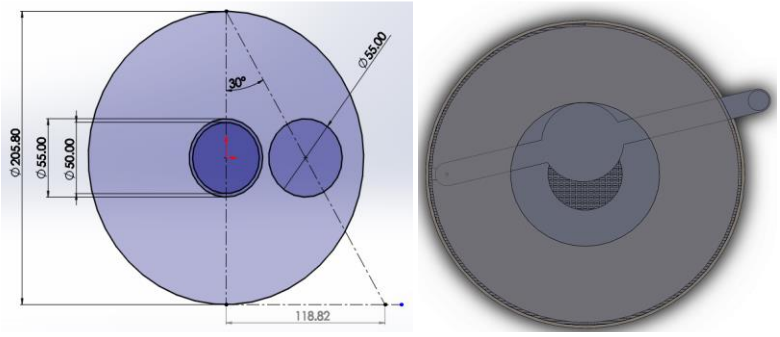

Figure 3: Flame Switch Design

2.7.4 Ceramic Fiberglass Insulation Blanket and Fibreglass cloth

The ceramic fiberglass insulation blanket which serves as a gel reservoir (Figure 4) was selected because of its high temperature resistance of 1260^{0}C, light weight and high corrosion resistance. The fibreglass cloth which serves as a heat backing fibre was selected because of its high temperature resistance (1482^{0}C), lighter weight and high corrosion resistance.

2.8 Construction of the Bio-ethanol Gel Cookstove

The Bio-ethanol Gel Cookstove (Figure 5) was constructed using the 316L stainless steel. Other materials utilized include ceramic fibreglass insulation blanket, fibreglass cloth, steel wire, flame switch, inner lid, outer lid, shell, tripod, and gel.

The shell was cut to sizes and the flame switch pass was incorporated on it. The ceramic fiberglass insulation blanket was then fed into the shell at 90% high. The fiberglass cloth was placed on top of the blanket, while the steel wire was placed on top of the cloth. The steel wire and mounted flame switch were covered with an inner lid and outer lid respectively, and the tripod was mounted to complete the full assembly of the Bio-ethanol Gel Cookstove.

Figure 4: Ceramic Fiberglass Insulation Blanket and Fibreglass Cloth

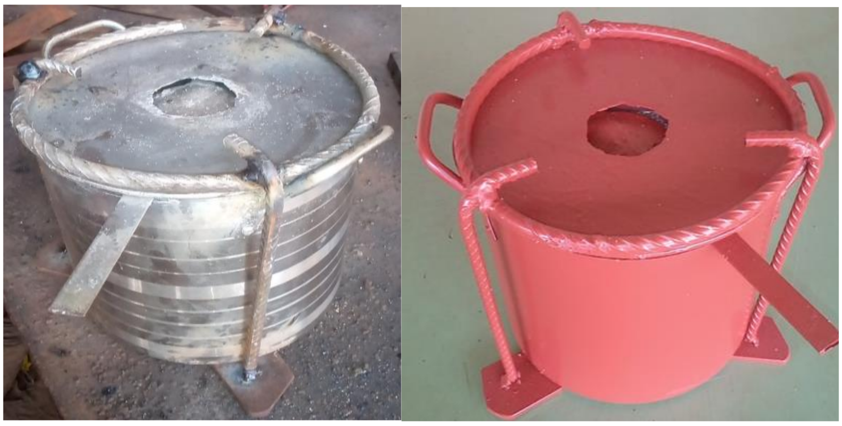

Figure 5: Bio-ethanol Gel Cookstove with tripod

3 RESULTS AND DISCUSSION

Bio-ethanol Gel Cookstoves are characterized by their square deal of low emission impact on the environment with good quality, simple design, easy to use and continuous operation. The combustion time test, the Residual test and the water boiling test was utilized to compare the performance of the Bio-ethanol Gel Cookstove to traditional or conventional kerosene stoves with the same test conditions.

The combustion time test aims to see the ability of bio-ethanol gel to burn until only part that cannot be burnt again, remains and is calculated for a long time until the fire is completely extinguished. The results of measurement of combustion time of bio-ethanol gel are presented in Table 1.

The result above showed that there is a difference in combustion time of 60ml of bio-ethanol gel with stove and without stove. Based on the results tests that have been done shows that the highest combustion time of 38 and 10 seconds was achieved at 60ml bio-ethanol gel with stove and without stove respectively. This implied that it took less combustion time without stove as compared to using stove. The trend of the result showed that the higher the quantity of the bio-ethanol gel the higher the combustion time both with and without stove. Therefore, more time is needed to combust more quantity of bio-ethanol gel. It means that combustion time is directly proportional to the quantity of bio-ethanol gel. The result of the study is in agreement with the findings of Hermawan and Sudarmanta [18]. Also, the gel stove cooks slowly with stove and faster without stove.

This test is done to find out how much residue is produced. Residue is part of the gel that is not completely burnt and is left behind after the combustion, changes, or reactions are complete. The residual test results are presented in Table 2.

Table 1: Combustion time test of 60ml Bio-ethanol gel

S/N	Bioethanol gel (ml)	Combustion time (sec.) with stove	Combustion time (sec.) without stove
1	10	4	2
2	20	8	3
3	30	12	5
4	40	14	6
5	50	28	9
6	60	38	10

Table 2: Residual test of 60ml Bio-ethanol gel

S/N	Bioethanol gel (ml)	Weight of Residue (g)
1	10	0.1
2	20	0.3
3	30	0.4
4	40	0.2
5	50	0.8
6	60	0.4

A cookstove is meant to burn the fuel completely and transfer all the heat evolved to the cooking pot. However, this does not happen during actual operation due to poor combustion and heat losses. The result of the residual test revealed that 60ml bio-ethanol gel had the highest weight of residue of 0.8g at 50ml and the lowest weight of residue of 0.1g at 10ml.

Furthermore, water boiling test “A” is a test that determines the performance of bio-ethanol gel, so that it can be used as a household fuel. In this water boiling test, not all bio-ethanol gel formulas were used, but the best sample was taken, namely the addition of bio-ethanol gel 60ml which was then compared with other fuels such as: kerosene and spiritus. The water boiling test results are presented in Table 3.

The result revealed that spiritus took more time to boil as compared with the other fuels. Bio-ethanol gel boiled faster than the other fuels while kerosene burnt moderately. A water boiling test ‘’B’’ is a test that determines the performance of bio-ethanol gel stove, so that it can be used as a household stove. The water boiling test results are presented in Table 4and Table 5. The results in table 4 covers Gel Stove Cold – Hot Test, Gel Stove Hot – Cold Test, Kerosene Stove Cold - Hot Test and Kerosene Stove Hot - Cold Test.

Table 3: Water boiling test of 60ml (Bio-ethanol gel, Kerosene, Spiritus)

Fuels	Fuels Volume (ml)	Initial Water Temperature (°C)	Final Water Temperature (°C)	Water Boiling Time (sec.)
Bioethanol gel	60	24	100	3
Kerosene	60	24	100	2
Spiritus	60	24	100	7

The study revealed that there is a direct proportionality between time and the gel stove cold – hot temperature. At the initial time of zero, the temperature was 27°C.At 6 minutes; the temperature was 75°C while at 14 minutes the temperature was 100°C. Calorific value of the fuel was taken as: Bf = 15.1kj/g. The gel stove hot – cold test result showed that at the initial temperature, the temperature was 58°C, at 4 minutes, the temperature was 64°C at 10 minutes boiling time, and the temperature was 79°C. Finally, at 14 minutes temperature, the temperature was 93°C at fuel calorific value of 15.1kj/g. For the Kerosene Stove Cold - Hot Test, at initial time of zero, the temperature was 26°C, at 4 minutes, the temperature 53 minutes while at 10 minutes the temperature was 90°C, the study reported that at 12 minutes the temperature was 96°C, while at 14 minutes of cooking, the temperature was 98°C. The calorific value of the fuel was taken as: B_f = 15.1kj/g. Lastly, for the Kerosene Stove Hot - Cold Test, findings of the study showed that as the heating time increased it was observed that the kerosene stove temperature increased. The trend revealed a proportionality relationship between the boiling time and the temperature. The study adopted the calorific value of the fuel as15.1kj/g.

Table 4: Water boiling test B of 190ml of water

Time (min)	Gel Stove Cold – Hot Temperature (℃)	Gel Stove Hot – Cold Temperature (℃)	Kerosene Stove Cold – Hot Temperature (℃)	Kerosene Stove Hot - Cold Temperature (℃)
0	27	58	26	56
2	44	60	39	59
4	60	64	53	63
6	75	68	70	66
8	87	72	84	68
10	94	79	90	75
12	98	85	96	81
14	100	93	98	91

Table 5: Results of Evaporation Test

Time (min)	Mass of water evaporated (g) (Gel Stove)	Mass of water evaporated(g) (Kerosene Stove)	Mass of fuel consumed(g) (Gel Stove)	Mass of fuel consumed(g) (Kerosene Stove)
5	189	189	57	58
10	186	169	56.5	55
15	174	140	55	51
20	172	133	54	49
25	158	121	43.2	43
30	134	110	32.7	39
Total	**M_e = 1013**	**M_e = 862**	**M_f = 298.4**	**M_f = 295**

Evaporation test of the study revealed that at 5 minutes, mass of water of evaporated gel stove and kerosene stove was constant (189g) while the mass of fuel consumed for gel stove was lower than the mass of fuel consumed by kerosene stove. At 10 minutes cooking time, the mass of water evaporated by gel stove (186) was higher than the one of kerosene stove (169g). At 15 minutes, the mass of water evaporated for gel stove 174g while that of kerosene was 140g. The trend of the result points to the fact that the boiling time decreased with increased mass of water evaporated for gel stove and kerosene stove. The same trend was observed in the mass of fuel consumed (g) in the gel stove and kerosene stove. The mass of fuel consumed (g) in the gel stove was higher and kerosene stove at equal boiling time. The calorific value of the fuel was taken as: B_f = 15.1kj/g.

4 CONCLUSION

In this research, an improved stove that uses bio-ethanol gel as fuel was developed. The physical-chemical properties associated with bio-ethanol gel fuel performance were determined in comparison existing stoves. The study focused on the potential of the improved stove in addressing fuel efficiency, environmental and human health impacts during utilization of bio-ethanol gel fuels. The vermiculite insulation with a low thermal conductivity of 0.17 W/m.K maintains the combustion temperature high (691°C). The higher heating value of bio-ethanol gel fuel stood at 18.5 MJ/kg with performance of the improved stove, in efficiency was obtained as75%. The combustion temperatures of the improved stove were 12.8% better than the existing stoves.

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